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Interactive comment on "A new methodology to train fracture network simulation using Multiple Point Statistic" *by* Pierre-Olivier Bruna et al.

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Dear Reviewer

First let us thank you very much for the interesting and constructive comments you left on our paper. This letter aims to reply to your specific comments concerning our manuscript

1) This paper presents a specific application of multipoint statistics to generate synthetic non-stationary 2-D DFN models. I don't think that this is the _first_ application of MPS - I seem to remember a number of authors using e.g., SGEMS for generating conditioned fracture fields.

As far as we were aware of we were the first proposing a MPS approach using the

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Discussion paper

Direct Sampling algorithm were multiple training images are used at time in order to predict the geometry of fracture networks in a non-stationary manner. We also developed our own Matlab codes to generate probability maps or to extract segments out of a MPS realisation (image). We are aware about the fact that people in the past tried to model fracture networks using MPS method however they used single training image that should represent the whole variability of the network. After looking specifically for similar work associated to the laboratory developing SGEMs we were unfortunately not able to find any results suggesting that our approach was already tested. If the reviewer can provide specific references we will be very pleased to take them into consideration and to eventually change the title of our article.

We do not think that particular action in the manuscript are required from the reviewer concerning this issue

2) It is greatly appreciated that the paper clearly explains the limitations of the approach, particularly problems in identifying longer fractures. In addition, there are problems in 3D extrapolation, non-planar features, and termination modes.

Thank you for this comment. Indeed we do have some limitations however we are working on methods for solving some of the problems you are mentioning and we hope to be able to release them as publications in the near future.

We do not think that particular action in the manuscript are required from the reviewer concerning this issue

3) In evaluating the generated DFN's, it would be appropriate to quantitatively compare the statistics of generated vs training DFN's in terms of: Intensity spatial distribution as P21 m/mËĘ2, orientation distribution for each set, and size (trace length) distribution, and termination modes.

In this paper we made a sensitivity analysis comparing the reference data (fracture tracing made by a geologist on high-resolution drone imagery) with the realisations we obtained. In this part of the work we compared the amount of segments and their length distribution to evaluate if the realisations are good enough or not. We also used a non-standard approach using the Barton-Bandis stress induced aperture calculation to compare some of the best realisations with the reference outcrop. While, we think that all of those tests are sufficient to show that the approach is giving satisfactory results in this specific case,

We agree to add to our revised manuscript some P21 calculation conducted on the 5 selected realisations presented in figure 14. This part will be inserted just before the section IV on uncertainties

4) I don't understand why the engineering aspects of the project (i.e, using Barton's empirical relationship to define aperture, geomechanical and flow simulations)- are included in the paper. This is a theoretical algorithm paper, not a case study. Perhaps the engineering portions can be put in a separate paper?

Indeed, this attempt of validation of our MPS results is not a conventional way of doing it. However, we strongly believe that calculating fracture aperture has a double interest. Intrinsically the method allows obtaining realistic estimations of fracture apertures in a non-stationary fracture network. These kind of data cannot be obtained directly from observation in the field and getting these data is of primary importance for fluid flow calculations. Secondly, fracture aperture in Apodi outcrops were already calculated by Bisdom et al., 2016, and we wanted to use this work as a base to compare the results of our simulation. By doing so we demonstrated that reference and trained networks behave equally. Indeed they provide similar ranges of apertures and tend to locate open fractures in the same areas. We believe that this approach is an original and interesting way to validate the results of the MPS.

However following similar comments from the other reviewer we decided to remove this part from the manuscript

5) I would appreciate more details on the specifics of the MPS implementation. I don't

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think that the algorithm could be reproduced by others with just the details provided in the paper. How is MPS used to vary fracture intensity? Trace length? Orientation? How is MPS used to for different sets, or are the sets completely independent models?

As previously mentioned by Journel, 2003 or by Strebelle 2002, the key factor in MPS simulation is the training image used to generate the model. This is why some authors like Hu et al., 2014 use a full reservoir model as training image. In that case all of the heterogeneity is considered and the statistical variability is implicitly generated – among others – during the scanning of the training image. The idea of our paper is to use fracture facies corresponding to the different sets of fractures identified in an entire outcrop – in our case 3 – and to use multiple sketches to vary the parameters you are talking about: the intensity, the length of fracture the crosscutting relationship and more. If you check into figure 5 for instance, you will see that the training images carry a lot of implicit information gathered from field based investigations for instance or from the interpretation of the network from the drone image. The result obtained showed that the algorithm is able to reproduce this variability during the MPS process. We thought that this part is well explained in the "Method" part under "Multiscale fracture attributes" and "Training images, conditioning data and probability map" chapter. However if we do need to rewrite this paragraph we will be pleased to do it on the revised version of our manuscript.

We decided to add a piece of pseudocode in the manuscript as supplementary material to help people to be able to better understand what DS is doing. The following pseudocode is suggested

The DeeSse algorithm (Straubhaar, 2011) was used in this paper to reproduce existing fracture network interpreted from outcrop pavements. The following pseudocode developed by Oriani et al., 2017 have been modified to explains how the algorithm is processing the simulation of fracture. Specific terms can be found in section II.1 of the present paper. In our study the simulation follow a random path into the simulation grid. This grid is step by step populated by pixels y sampled in the training image until the

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simulation grid is entirely filled by properties called V(x) (fracture facies in this case). The algorithm proceeds according to the following sequence

1. Selection of a random location x in the simulation grid that has not yet been simulated (far from any conditioning data already inserted in the grid)

2. To simulate V(x) → the fracture facies into the simulation grid: retrieve a data event dn(x), corresponding to n neighbours around x thanks to a fixed circular spatial window of radius R. The pattern dn(x) = (x1,V(x1)),. . .,(xn,V(xn)) formed by at most n informed nodes the closest to x is retrieved. If no neighbours is assigned (at the beginning of the simulation) and dn(x) will then be empty: In this case, assign the value V(y) of a random location y to V(x), and repeat the procedure from the beginning.

3. Visit a random location y in the TI and retrieve the corresponding data event dn(y).

4. Compare dn(x) to dn(y) using a distance D(dn(x), dn(y)) corresponding to a measure of dissimilarity between the two data events.

5. If D(dn(x), dn(y)) is smaller than a user-defined acceptance threshold T, the value of V(y)is assigned to V(x). Otherwise step 3 to step 5 are repeated until the value is assigned or an given fraction of the TI, F is scanned.

6. if F is scanned, V(x) are defined as the scanned datum that minimise the distance D(dn(x), dn(y)) within the simulation grid.

7. Repeat the whole procedure until all the simulation grid is informed.

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